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Least-Squares Strategy for Analyzing Pogson's Step Method

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Pogson's step method has been widely used in (especially visual) observations of variable stars. The "textbook" reduction procedure for this method is often rather empirical: 1) first determine the difference in steps between pairs of comparison stars of nearest magnitudes, 2) second determine the brightness of the variable star by using the step values of comparison stars. This usual procedure introduces some ambiguity in selecting pairs from the whole sample of comparison stars, and some biases caused by inhomogeneous usage of individual comparison stars. I present a more robust, least-squares strategy for analyzing Pogson's step method, which simultaneously solves the step values of comparison stars and the variable star.

The usual expression of Pogson's method (1) tells that the variable was observed two steps fainter than comparison a, one step brighter than comparison b and three steps brighter than comparison c.

$$a2v\ v1b\ v3c \tag{1}$$

In this strategy, we set step values of comparisons a, b, etc. as m_a, m_b, etc. The step value of the variable star at time t_i is expressed as v_i. In the sample (1) we can get a set of equations:

$$\begin{aligned} v_1 - m_a &= 2 + \epsilon_1 \ , \\ v_1 - m_b &= -1 + \epsilon_2 \ , \\ v_1 - m_c &= -3 + \epsilon_3 \end{aligned} \tag{2}$$

Similar formalism can be applied to a set of observations giving a set of equations:

$$v_i - m_j = s_{ij} + \epsilon_{ij} \tag{3}$$

for all set of observation $(t = t_i)$ and comparison star j.

By applying the least-squares regime, we define the square sum of residuals

$$S = \sum_{i,j} {\epsilon_{ij}}^2 \tag{4}$$

where the summation represents the sum over all set of individual step estimates.

To minimize S, we then have to solve the following equations:

$$\begin{aligned} \frac{\partial S}{\partial v_i} &= 0 \ , \\ \frac{\partial S}{\partial m_j} &= 0 \end{aligned} \tag{5}$$

Eq. 5 yields a set of normal equations with unknowns v_i and m_j. In order to reduce the equations, the first set of equations ($\frac{\partial S}{\partial v_i} = 0$) are used to represent v_i by m_j:

$$v_i = \frac{1}{N_i} \sum_j (m_i + s_{ij}) \tag{6}$$

where N_i represents number of comparison stars used at $t = t_i$. By replacing v_i by eq. 6, eq. 5 yields a reduced set of normal equations having unknowns m_j.

$$\sum_j a_{ij} m_j = \sum_i s_{ij} - \sum_i \frac{1}{N_i} \sum_k s_{ik} \tag{7}$$

where $a_{ij} = \frac{1}{N_i} - 1 (i = j)$, $\frac{1}{N_i} (i \neq j)$.

As is evident from the definition, all m_j are not independent. So one of these normal equations in eq. 7 can be replaced by defining the zero point:

$$m_0 = 0 \tag{8}$$

A C source program to convert observations to these normal equations to solve them, together with a DOS executable is available at the URL:

ftp://ftp.kusastro.kyoto-u.ac.jp/pub/vsnet/others/prog/step.

Reanalysis of Photographic Observations of CY UMa in 1988

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1. Introduction

CY UMa was discovered as a dwarf nova by Goranskij (1977). CY UMa was first claimed to be an SU UMa-type, ultrashort orbital-period dwarf nova by photographic and visual observations (Kato et al. 1988). Their suggested superhump period of 0.0593 d, however, was disproved by the later CCD observations giving superhump periods of 0.0719 ± 0.0005 d (Kato 1995) during two superoutbursts in December, 1991 – January, 1992 and in March, 1993, and later 0.07210 ± 0.00003 d (Harvey, Patterson 1995) during the March, 1995 superoutburst. The author tested whether this superhump period was observed on the 1988 January occasion.

Among the data from the VSOLJ database, I used Fujino's time-resolved photographic photometry for the following analysis. The data were taken on 1988 November 11, 13 and 14. The total number of estimates was 284. Fujino used his own sequence which he had calibrated photographically using Huruhata's variable star charts.

2. Analysis

The resultant light curve is shown in Figure 1, which shows a characteristic slow decline seen in the later stage of a superoutburst.

After applying heliocentric corrections and removing a general trend of decline, the data were analyzed using the Phase Dispersion Minimization (PDM) method (Stellingwerf 1978). The resultant theta diagram (Figure 2) clearly shows the existence of superhump variation near the frequency of 13.8 d^{-1}, and rather disproves our earlier analysis (Kato et al. 1988). Adjacent signals near 12.8 d^{-1} and 14.8 d^{-1} are one-day aliases resulting from the short nightly coverage. The best determined frequency (disregarding the possibilities of aliasing) was 13.76 d^{-1}, corresponding to the superhump period of 0.0727 d.

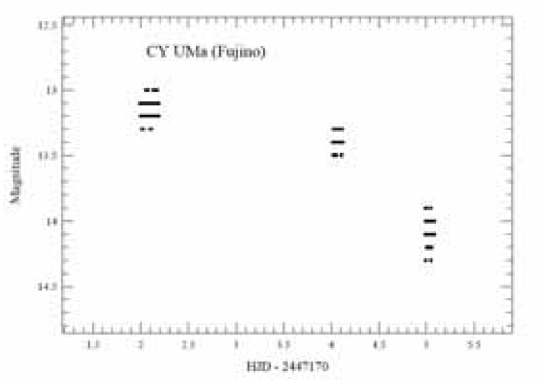

Figure 1. Light curve of CY UMa

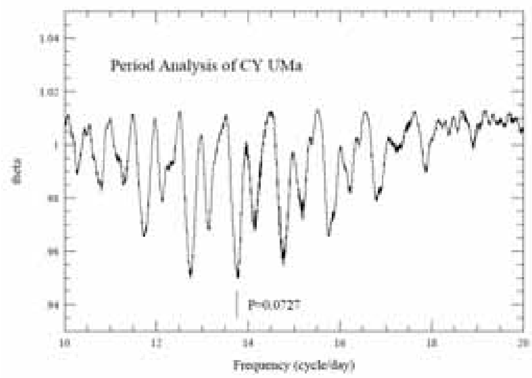

Figure 2. Period analysis of CY UMa

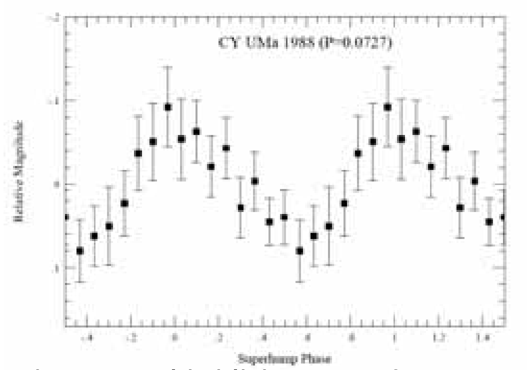

Figure 3. Folded light curve of CY UMa

This result confirmed superhumps were actually detected by Fujino's photographic photometry, and retrospectively demonstrates the efficacy of skilled photographic photometry of detecting small amplitude variation like superhumps. The folded light curve (Figure 3) shows a typical superhump light curve having a steeper rise and a slower decline. The total amplitude of superhumps was 0.17mag.

Acknowledgments. This work has been based on the VSOLJ Database. The author is grateful to the VSOLJ staffs, and to S. Fujino, without his extraordinarily skillful observations, this star would not have received that timely attention as early as in 1988.

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Prediscovery Photographic Observation of V4334 Sgr (Sakurai's Object)

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S. Sakurai discovered the final helium flash candidate, V4334 Sgr on Feb. 20.806 UT, 1996 (IAUC 6322). I examined my patrol films and measured prediscovry photographic magnitude of this star. The observations done at Saku Observatory (Saku-machi, Nagano, Japan), using twin 10-cm patrol cameras (PENTAX 100SDUF, fl=400mm) and T-Max400 films. The magnitudes were determined against neighboring GSC stars.

Table 1. Observations of V4334 Sgr before discovery

JD-2400000	mag	JD-2400000	mag	JD-2400000	mag
49457.1618	<15.5	49647.9028	<15.0	49759.3118	12.4
49775.2854	12.4	49783.2618	12.2	49788.2528	12.3
49831.2076	12.3	49834.2479	12.2	49860.1424	11.8
49870.1306	12.0	49888.1118	11.9	49922.0660	11.4
49943.9618	11.3	50003.9347	11.4	50015.8910	11.2
50135.3028	11.3				

Note: These data have been reported as Vsnet-alert 341 (http://kusastro.kyoto-u.ac.jp/vsnet /Mail/vsnet-alert/msg00341.html), previously.

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